# CHARACTERIZATION, MAGNITUDE AND IMPACT OF URBAN RUNOFF IN THE GRAND RIVER BASIN



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# CHARACTERIZATION, MAGNITUDE AND IMPACT OF URBAN RUNOFF IN THE GRAND RIVER BASIN

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## INTRODUCTION

The general goals of the Grand River Basin Water Management Study are:

1- to develop viable water management options needed to plan for, and encourage, the integrated use of water and land resources, within the Grand River Basin.

2- to identify the necessary trade-offs to achieve protection against flooding, acceptable disposal and transport of waste effluents.

3- to provide adequate supplies of good quality water to meet water supply, aesthetic, fish, wildlife and recreation desires and needs.

4- to ensure a productive and fulfilling environment for the people of the basin.

In summary, the three water management objectives of the Grand River Basin Study are to reduce flood damages, to provide adequate water supply and to maintain an acceptable water quality.

Water quality constitutes an important component of the study. The key elements of water quality investigation are:

1- to determine existing water quality conditions and relate them to various water uses.

2- to identify the type, magnitude, relative significance and impact of pollutants from point and nonpoint (urban and rural) sources on the water quality of the river.

3- to develop water quality management programs to preserve areas of high water quality and to upgrade areas where poorer water quality exists.

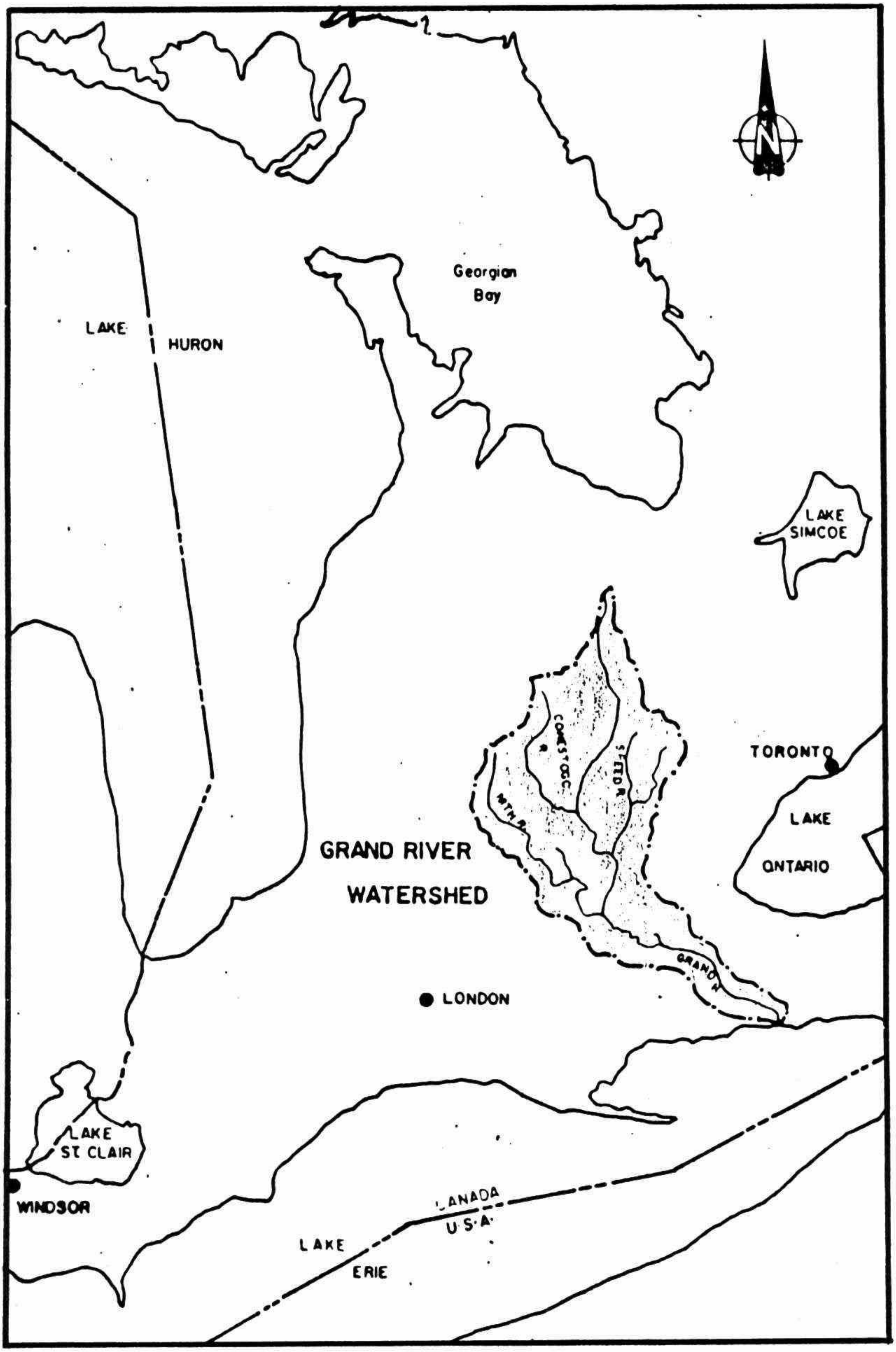


Figure 1. Location of the Grand River Basin in Southwestern Ontario.

Urban stormwater runoff has been recognized as a potential major contributor of pollution to the Grand River. Therefore, investigation of pollution from urban sources became an integral part of the basin's water quality assessment program. Because costs associated with the abatement of urban stormwater pollution range in the tens of millions of dollars it was important to assess the impact of this pollution on the river and to determine its significance.

This paper contains a description of the Grand River Basin and its major urban centres and an overview of urban data collection programs. Significant results to date related to the characterization of urban runoff, magnitude of pollution loads and their impact on the Grand River are presented.

## DESCRIPTION OF THE GRAND RIVER BASIN

The Grand River Basin is located in southwestern Ontario between longitudes $79^{o}$ 30' and $80^{o}$ 57' W, and latitudes $42^{o}$ 51' and $44^{o}$ 13' N. The basin occupies the central part of a peninsula bounded on the north by Georgian Bay, on the west by Lake Huron, on the south by Lake Erie and on the east by Lake Ontario (Figure 1). The basin has an area of about 6,700 $km^2$, a length of about 290 km and a width which varies between 5 and 75 km.

The headwaters of the Grand River rise in a massive swampy upland south of Georgian Bay at an elevation of approximately 526 m above mean sea level (msl). The river flows in a southerly direction until it reaches the Town of Paris. From there it follows a southeasterly direction to discharge into Lake Erie at Port Maitland at an elevation of 174 m above msl. The Conestogo, Speed and Nith rivers are the three major tributaries which join the main stem in the middle portion of the basin. The Conestogo River drains the northwestern portion of the basin with the Speed and Nith rivers draining the eastern and western portions of the basin, respectively. In the upper part of the basin, the Grand and its tributaries flow in previously formed glacial spillway channels. In

the lower part, below the City of Brantford, the river has scoured its own channel across glacial lake deposits of silt and clay.

The drainage basin is characterized by a temperate climate that receives a moderating influence from the nearby Great Lakes System. The long-term mean annual temperatures vary from $6^{\circ}C$ in the headwaters to $9^{\circ}C$ at Lake Erie. The long-term mean annual precipitation varies from 84 cm (178 cm snow) in the lower reaches to 88 cm (127 cm snow) in the upper reaches of the basin.

The mean annual flow at the outlet of the river is estimated to be 64 $m^3/s$ which corresponds to a mean annual runoff of 30 cm of precipitation. Peak flows range from 500 to 1400 $m^3/s$. In general, peak flows occur during the spring melt period. The highest flow on record, however, occurred as a result of Hurricane Hazel in November of 1954.

## LAND USE, POPULATION AND MAJOR URBAN CENTRES

The Grand River Basin has been developed extensively for urban and agricultural uses which comprise 3% and 75% of the total basin area, respectively. Wooded and/or idle areas account for approximately 19% of the basin area and the remaining 3% lies in other uses. Urban uses are predominant in the central portion of the basin where the cities of Kitchener, Waterloo, Guelph, Cambridge and Brantford are located (Figure 2).

The population of the basin is approximately 545,000 and is primarily concentrated in the above mentioned five large urban centres. This, however, was not always the case. In 1921, 43% of the basin's population was rural and only 47.5% lived in the five urban centres (Table 1). By 1976, however, the proportion of rural population dropped to about 20% whereas the proportion of population in the five urban centres increased to 72%. If these trends continue through subsequent years, it can be expected that the urban population by the year 2001 might increase by about 200,000 to 300,000 people. This could increase pollution loadings to streams

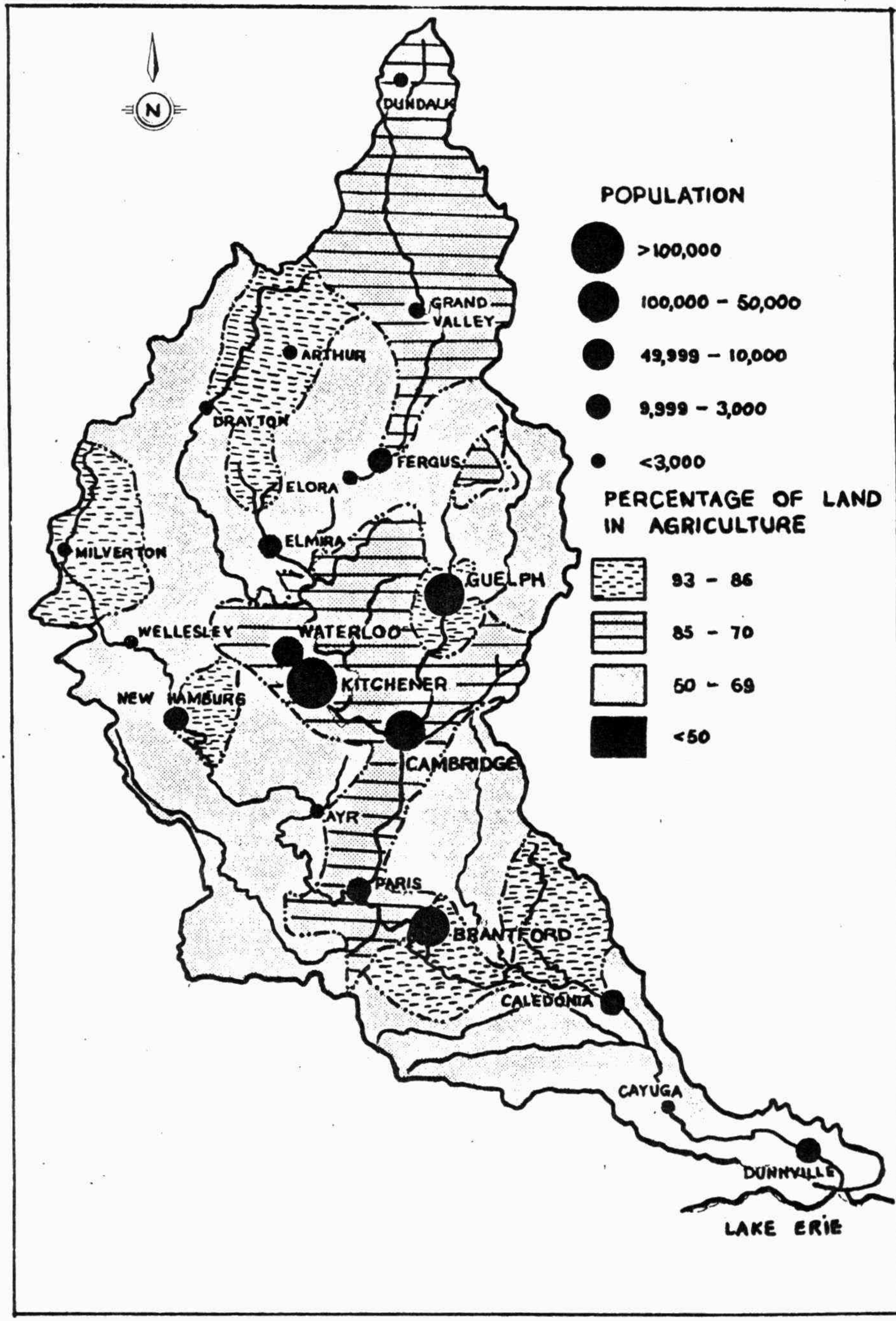


Figure 2. Population and Land Use Distribution in the Grand River Basin.

from urban runoff, further impair water quality conditions and tax available water supplies.

At present, water quality problems in the upper or northern third of the basin, where agriculture is predominant, are related primarily to erosion. Soils and nutrients are carried into the river causing turbidity, nutrient enrichment and limited localized algal growth. The algal density (bottom cover) varies from 0-80% coverage of the streambed (Figure 3). With the exception of localized aquatic growth, water quality problems in this part of the basin are usually limited in extent and do not have significant detrimental impact on river uses.

The heavily urbanized and industrialized central third of the basin is significantly affected by the discharge of treated domestic and industrial wastes and urban stormwater runoff. Two of the major problems that have been identified through the Grand River Study are: 1) the reduction of dissolved oxygen in areas downstream from the major municipalities caused by municipal discharges of oxygen-consuming wastes; and 2) profuse algae and plant growths stimulated by nutrient inputs from point and nonpoint sources.

The lands of the lower third of the basin and the Nith River, a major tributary draining the western portion of the watershed, are primarily used for agriculture and the problems encountered there are quite similar to those identified earlier for the northern third of the watershed (Jeffs et al, 1978).

The land use distribution and drainage systems in the five major cities in the basin are described in the following sections.

<u>Brantford</u> - The City of Brantford is located on the Grand River approximately 91 km north of Lake Erie. The City has a developed area of 3214 ha. and it is served by separate sanitary and storm sewer systems. Approximately 30% of the city area is drained via the storm sewer system directly to the Grand River, 35% to Fairchild's Creek, 30% to Mohawk Creek, 3% to Paper Mill Creek and

TABLE 1 POPULATION IN THE GRAND RIVER BASIN

| | | | | | Population Projections for 2001** | |
|---|---|---|---|---|---|---|
| Cities | 1921 | 1941 | 1966 | 1976 | Low | Medium |
| Kitchener | 21,763 | 35,657 | 91,376 | 131,801 | 200,795 | 227,486 |
| Waterloo | 5,883 | 9,025 | 29,770 | 49,972 | 86,461 | 92,131 |
| Cambridge | 21,416 | 25,108 | 51,482 | 71,482 | 46,815 | 124,474 |
| Guelph | 18,128 | 23,273 | 49,497 | 70,374 | 90,250 | 115,456 |
| Brantford | 29,440 | 31,948 | 58,395 | 66,930 | 85,833 | 94,982 |
| Total | 96,630 | 125,011 | 280,520 | 390,599 | 588,159 | 649,529 |
| % of watershed population | 47.5 | 53.0 | 68.2 | 71.6 | 69.8 | N/A |
| Average Annual Growth Rate % | | 1.3 | 3.3 | 3.4 | 1.8* | 2.3* |
| Incorporated Towns and Villages | | | | | | |
| Total Population | 18,589 | 20,818 | 35,961 | 43,559 | 58,896 | 69,114 |
| % of watershed population | 9.1 | 8.8 | 8.7 | 8.0 | 7.3 | N/A |
| Average Annual Growth Rate % | | .6 | 2.2 | 2.1 | 1.57* | 2.27* |
| Rural Areas (including unincorporated rural hamlets) | | | | | | |
| Total population | 88,204 | 89,795 | 95,118 | 111,185 | 200,947 | N/A |
| % of watershed population | 43.4 | 38.0 | 23.1 | 20.4 | 22.9 | N/A |
| Average Annual Growth Rate % | | .09 | .23 | 1.5 | 1.81* | |
| Total watershed population | 203,423 | 235,624 | 411,599 | 535,051 | 877,137 | N/A |
| Average Annual Growth Rate % | | .74 | 2.3 | 2.8 | 1.92* | |

* Growth rates apply for the years between 1976 and 2001.
** Population projections based upon available data, March 7-79.

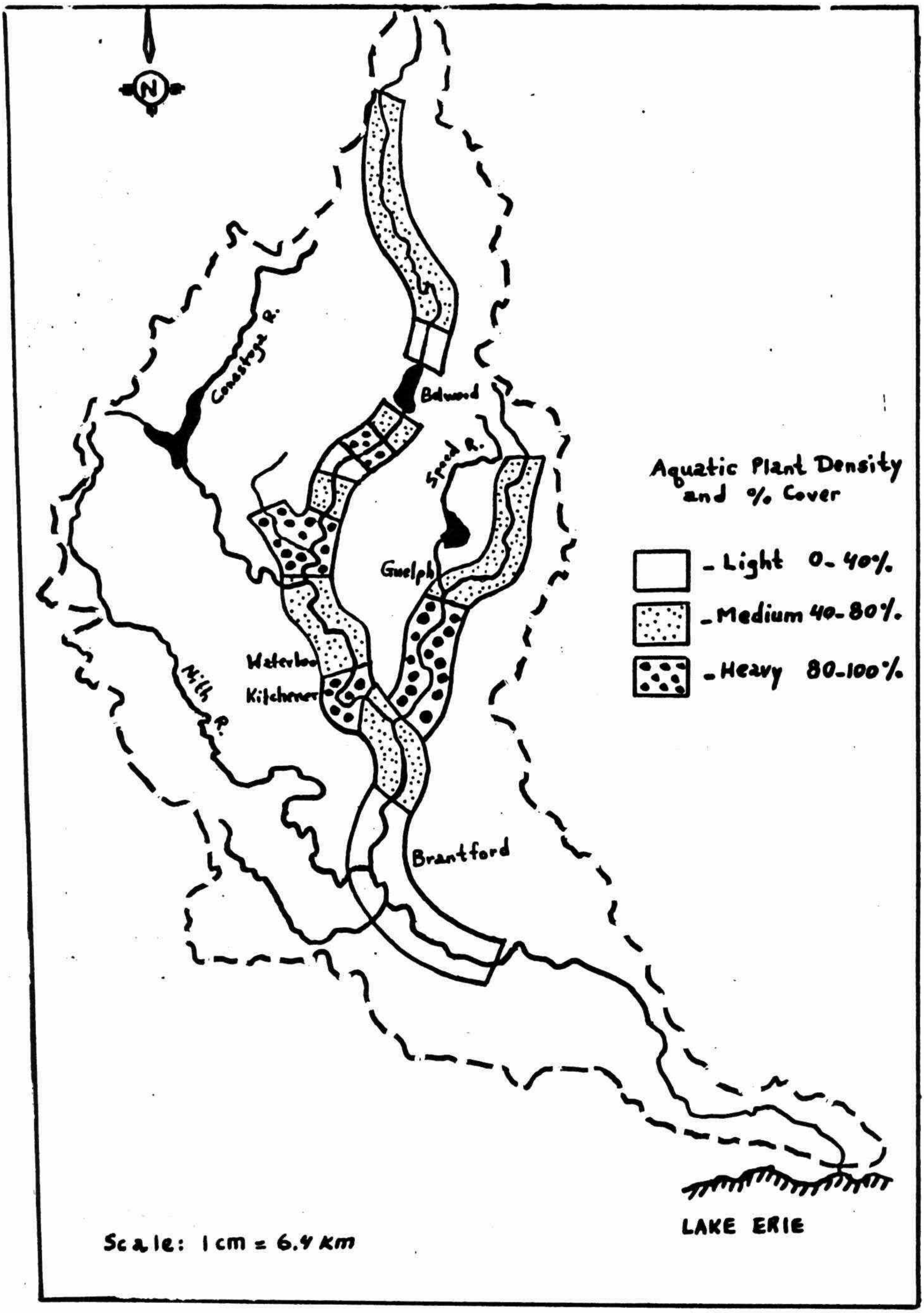


Figure 3. Aquatic Plants Density and Percent Coverage of Streambed in the Grand River.

2% to D'Aubigny Creek. The land uses are: residential 52.6%, commercial 4.9%, institutional 4.5%, industrial 16.0% and open space* 21.7%.

Brantford is the centre of agricultural machinery manufacturing in Canada and it produces a wide range of goods from chemicals, building products, pulp products, refrigeration units and construction machinery to school buses and transport trailers.

Cambridge - The City of Cambridge was created in 1973 as a result of the amalgamation of the towns of Hespeler, Preston and Galt. Hespeler lies 7.3 km upstream on the Speed River while Preston is located at the confluence of the Speed and Grand Rivers and Galt lies 6.3 km downstream on the Grand River. Cambridge has a total developed area of 3675 ha. The land uses are: residential 52.5%, commercial 10.3%, institutional 4.5%, industrial 14.0% and open space 18.7%.

Each of the three amalgamated towns has its own separate storm sewer system. The storm sewer system in Hespeler discharges to the Speed River whereas in Preston it discharges to both the Speed River (50%) and the Grand River (50%). Approximately 30% of storm runoff from Galt discharges to Galt Creek and the remaining 70% to the Grand River.

Guelph - Guelph is located at the confluence of the Speed and Eramosa Rivers. The city has a developed area of 3080 ha which has been divided into the following land uses: residential 50.5%, commercial 3.5%, institutional 12.8%, industrial 13.6% and open space 19.6%.

The City has completely separate sanitary and storm sewer systems. The storm sewer system discharges into the Speed River (70%) and Eramosa River (30%).

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* parks, cemeteries ... etc.

Modern stormwater management concepts are being implemented in some of the developing subdivisions in the city. Ponds are used in three new residential subdivisions for sedimentation and ground water recharge; another pond is under construction in a developing industrial zone.

Kitchener - Waterloo - The twin cities of Kitchener and Waterloo are located in the central part of the Grand River Basin. The cities have a combined developed area of 7864 ha which have the following land uses: residential 39.7%, commercial 5.9%, institutional 2.9%, industrial 14.7% and open space 36.8%.

The City of Waterloo is served by separate sanitary and storm sewer systems. The storm sewer system discharges at several locations along Laurel Creek and its tributaries. The City of Kitchener has essentially separate sanitary and storm sewer systems except in the old section of the City where house foundation drains are connected to the sanitary sewers because the storm sewers are placed at inadequate depths. Schneider Creek and its tributary, Montgomery Creek, receive about 80% of Kitchener's stormwater runoff while the remaining 20% drains directly to the Grand River. The Kitchener-Waterloo urban area has been heavily industrialized. Major economic activities include furniture, automotive, tire and shoe manufacturing, meat packing and other industries.

## DATA COLLECTION PROGRAMS

1 - MOE - COA Program - A data collection program on urban runoff in the Grand River Basin was initiated by the Ontario Ministry of the Environment (MOE) and supported by the Canada-Ontario Agreement on Great Lakes Water Quality (COA) for a duration of two years (1975-1976). Under this program, two urban catchments (the North and West catchments) were established in the City of Guelph and instrumented for quantity (precipitation and runoff) and quality monitoring.

The objectives of the program were to investigate the variation of

quantity and quality of stormwater runoff; to document the difficulties encountered in the selection and instrumentation of representative urban catchments and, to investigate the applicability of the Storage, Treatment, Overflow and Runoff Model (STORM) for prediction of urban runoff quantity and quality.

The North Catchment is located at the northern limits of the City of Guelph (Figure 4). The catchment is a relatively new suburban division consisting primarily of single family residential land use (82.9%) with minor areas of multiple family residential (3.5%), commercial and institutional (6.2%) and open space (3.3%). The area of the catchment is 58.8 ha with a total imperviousness of 39.0%.

The West Catchment (Figure 4) is adjacent to the downtown core of the City of Guelph. The catchment (234.8 ha) represents a range of various land uses, old and recently developed, consisting of single and multiple family residential (44.9%), commercial (3.1%), industrial 29.5% and open space 22.5%. The total imperviousness of the catchment was estimated at 32.3% (Novak, in press).

Precipitation in both catchments was measured using two Leopold and Stevens tipping bucket rain gauges of capacity of 0.254 mm. Flow measurements were made at the outlet of both catchments and samples were collected manually (during the first phase of the program) and using a manually activated automatic sampler (during the second phase of the program). Samples were analysed for the following parameters:

five-day biochemical oxygen demand,
chemical oxygen demand,
solids (total and suspended),
phosphorus (total and soluble),
nitrogen forms (free ammonia, Kjeldahl, nitrite and nitrate),
iron, lead, phenols, chloride, conductivity and coliforms
(total and fecal) and streptococcus sp.

During this program a total of 14 events were monitored in the North

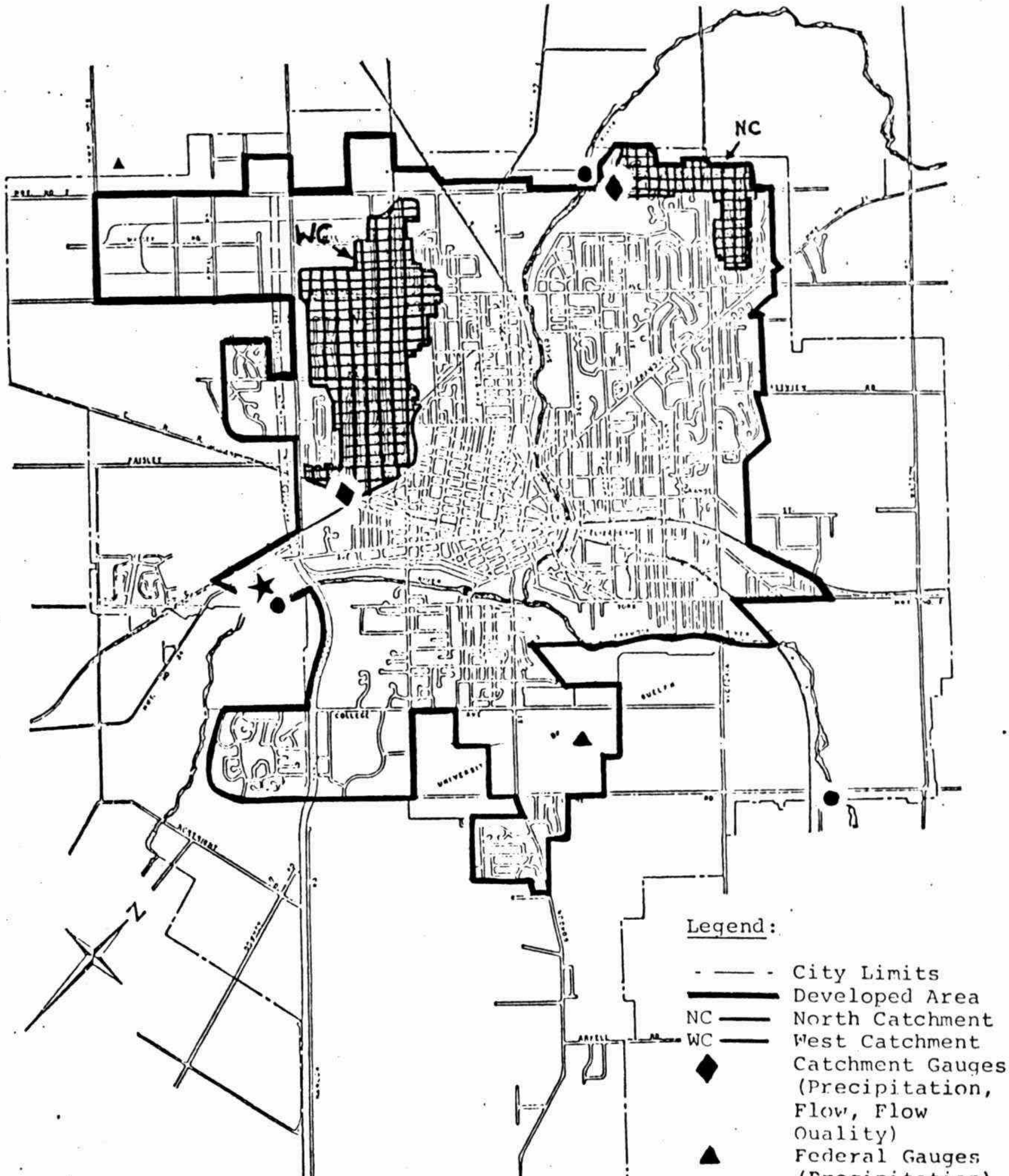


Figure 4.

Location of the Northern and Western Urban Catchments and Quantity and Quality Monitoring Stations in the City of Guelph (after Novak, 1979).

Catchment and 13 events in the West Catchment. Unfortunately, only four events in the North Catchment and two in the West Catchment were completely monitored in terms of precipitation, flow (hydrograph) and quality (pollutograph). The remaining events were partially monitored. This program clearly indicated that automatic sampling stations are essential for the successful conduct of any urban runoff quality investigation.

2 - PLUARG Program - A second data collection program on urban runoff was established in the Grand River Basin under the Pollution from Land Use Activities Reference Group (PLUARG) during the period (1975-1977). The objectives of this program were to determine the sources of pollutants within urban areas, estimate their magnitude in terms of unit-area loadings, determine their relative significance and investigate the nature of their transport from urban areas.

Three urban areas were selected in the Grand River Basin for the study, namely: the megalopolis of Kitchener-Waterloo-Cambridge, the City of Guelph and the Town of New Hamburg. In addition, two small urban watersheds were monitored, namely: Schneider Creek and Montgomery Creek. Monitoring stations were established upstream and downstream of the urban areas for the purpose of collecting flow and quality information for pollutant loading estimates (Figure 5). The difference between the pollutant load measured at the outlet (downstream) station, and the inflow (upstream) stations was considered to be the net pollutant load from the study area. The load from the urban sources was then estimated by subtracting measured point sources and other non-urban diffuse sources from the net pollutant load (O'Neill, 1979).

3 - The Grand River Basin Water Management Study Program - During the Grand River Basin Water Management Study monitoring of the quantity and quality of urban runoff continued in the Schneider Creek and Montgomery Creek watersheds. Flow data were obtained at the outlets of both watersheds and stream water samples were collected using two automatic samplers. Details of flow

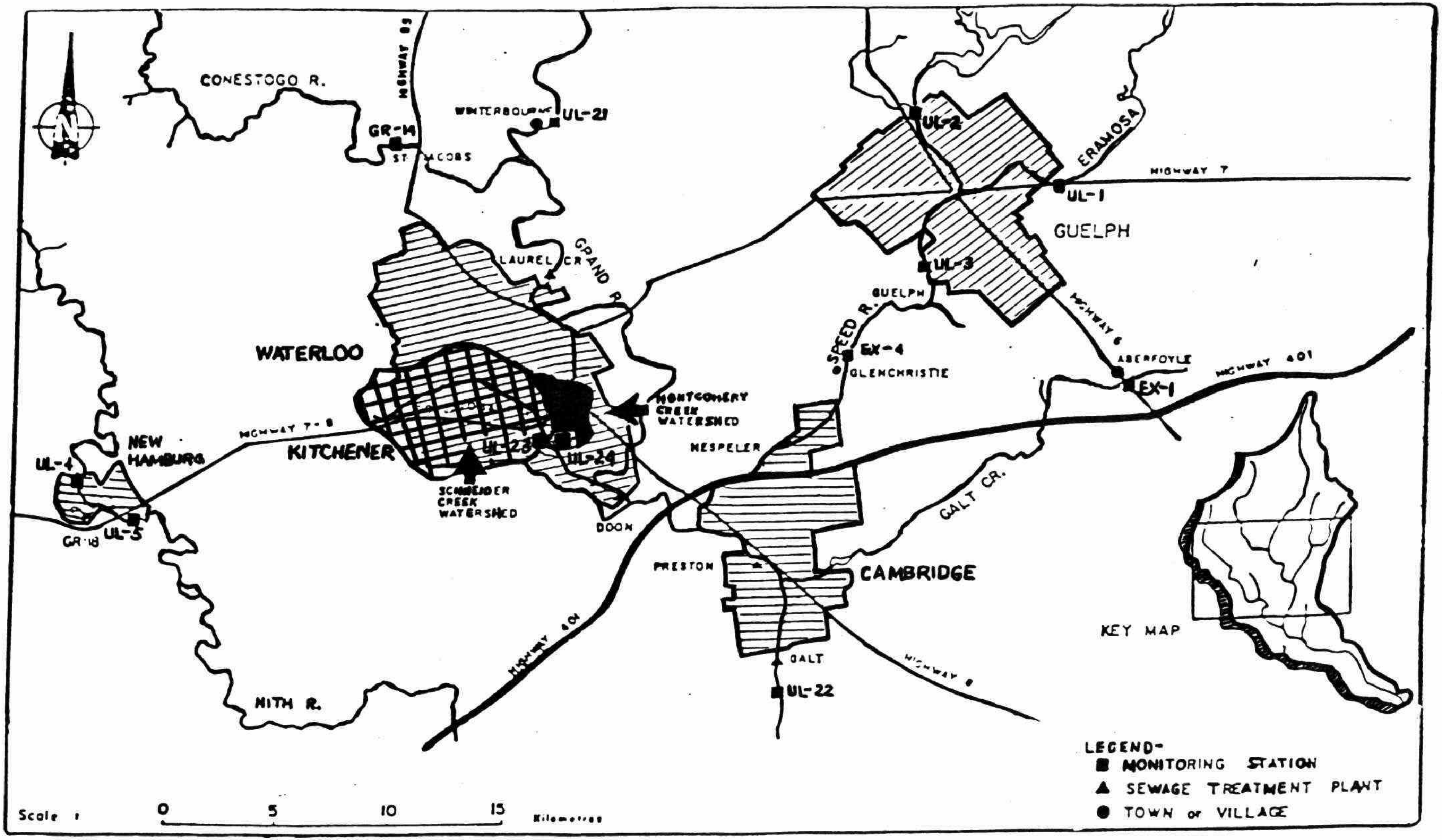


Figure 5. Urban Areas in the Grand River Basin Monitored Under the PLUARG Program.

measurements, sample collection techniques, handling and analytical procedures are discussed in detail in the methodology report (Onn, 1980).

Schneider Creek drains the western portion of the City of Kitchener (Figure 5). The drainage area is 3577 ha and consists of 60% urban, 35% agricultural and 5% wooded land. The major land uses in the urban area are: residential (primarily single family dwellings) 42%, commercial 5%, industrial 4%, recreational 8%, and transportation 1%. The watershed has an estimated population of 74,000 and is serviced by separate storm and sanitary sewer systems. The storm sewer system discharges at several locations along Schneider Creek.

Montgomery Creek drains the eastern portion of the City of Kitchener. The watershed has an area of 958 ha which consists of 96% urban and 4% wooded land. The major land uses in the urban area are: residential 64%, recreational 13%, commercial 12%, transportation 6% and industrial 1%. The watershed has a population of 58,000 and is serviced by separate storm and sanitary sewer systems. The storm sewer system empties into Montgomery Creek at several locations.

During the monitoring period a total of 22 hydrographs and 10 pollutographs were obtained for Schneider Creek and 14 hydrographs and 4 pollutographs for Montgomery Creek. The pollutographs, based on a sampling frequency ranging from 15 to 30 minutes, were produced for suspended solids, five-day biochemical oxygen demand, total phosphorus, filtered reactive phoshorus, total Kjeldahl nitrogen, filtered ammonia, chloride and lead.

In addition, at the time of initiation of the Grand River Basin Water Management Study in 1975, a network of seven continuous monitoring stations was established to monitor important water quality parameters in the central megalopolis area of the basin (Figure 6). Dissolved oxygen and temperature were monitored continuously at five stations using EIL (Electronic Instruments

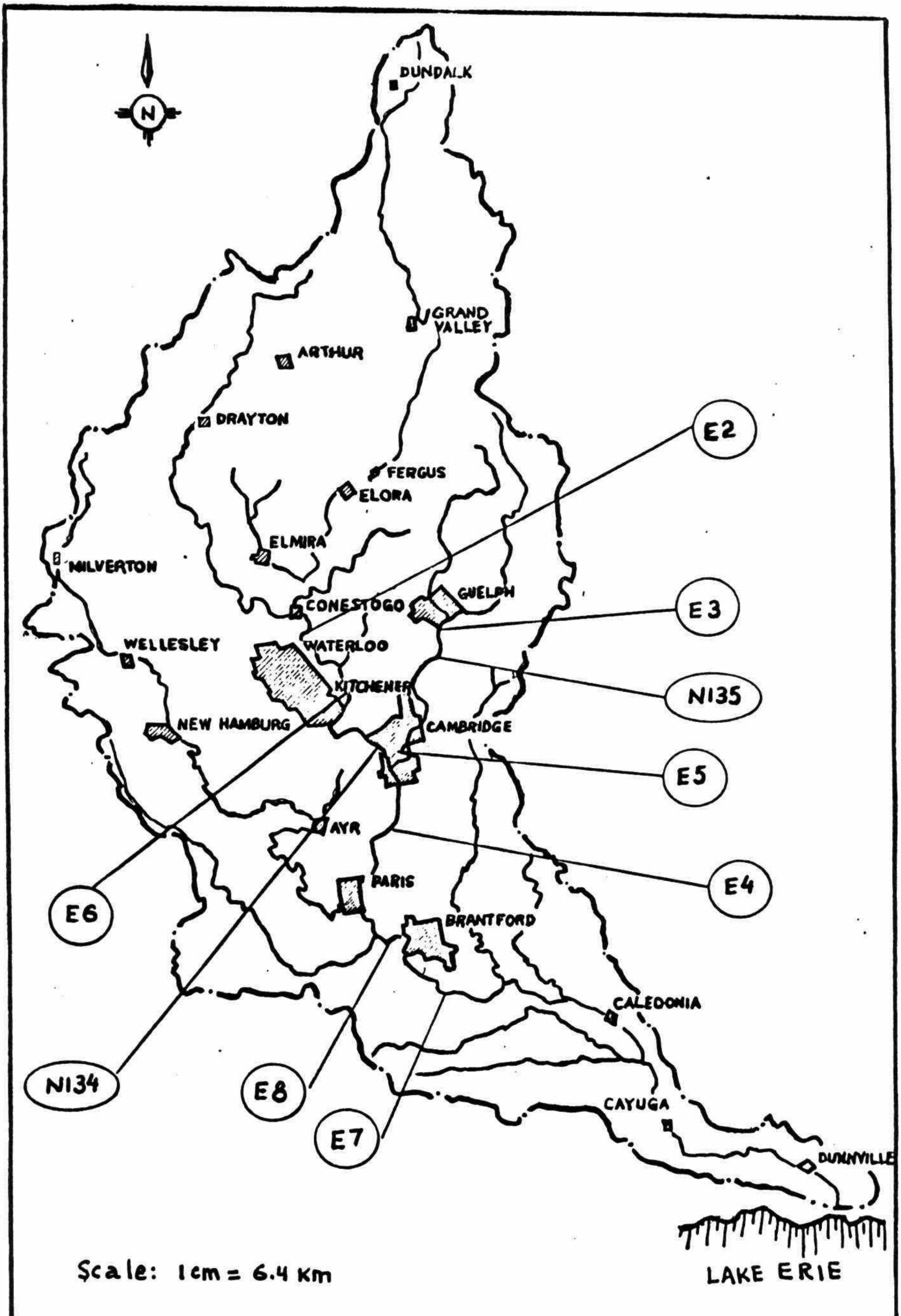


Figure 6. Continuous Monitoring Network in the Grand River Basin

Ltd.) instrument systems. At two other locations, NERA (New England Research Associates Inc.) instrument systems recorded dissolved oxygen, temperature, conductivity, pH and redox potential at half-hourly intervals (Draper et al, 1980). Data collected at these stations were used to calibrate and verify the Grand River Simulation Model (GRSM) and to assess the impacts of various pollution sources including urban runoff on the water quality of the Grand River.

## Characteristics of Urban Runoff

Since the PLUARG monitoring program was established to collect flow quantity and quality data for the estimation of annual pollutant loads, intensive sampling was not conducted at the monitoring stations during each storm event. As such, detailed runoff quality data are available only for a few storm events which occurred in the sampling period. For this reason, the characterization of urban runoff from the four test catchments relied primarily upon data generated from the other two monitoring programs. A statistical summary of the runoff quality data obtained is presented in Table 2.

Table 2 indicates that the quality data collected in each of the four test catchments span several orders of magnitude. These wide variations are in agreement with the characteristics of urban runoff reported for other cities in Ontario (Weatherbe and Novak, 1977) and can be attributed to the large number of factors known to affect the quality of urban runoff.

It can be seen in Table 2 that the concentrations of suspended solids and total phosphorus were highest in the runoff from the Schneider Creek watershed. The high suspended solids concentration values can be attributed to the construction activities in progress in the watershed during the monitoring period while the elevated concentration of phosphorus can be explained by the attachment of phosphorus on sediment particles. For undetermined reasons, the concentration of five-day biochemical oxygen demand was higher for the two test catchments in Guelph than in the Schneider Creek and Montgomery Creek watershed.

TABLE 2 STATISTICAL SUMMARY OF URBAN RUNOFF QUALITY DATA

| | Suspended Solids | 5-day Biochemical Oxygen Demand | Total Phosphorus | Total Nitrogen | Lead | Zinc | Chloride |
|---|---|---|---|---|---|---|---|
| 1. SCHNEIDER CREEK WATERSHED | | | | | | | |
| Mean mg/L | 267 | 3.9 | 0.66 | 3.04 | 0.08 | 0.78 | 66 |
| Standard Deviation, mg/L | 643 | 2.5 | 1.10 | 2.19 | 0.07 | 0.71 | 36 |
| Range, mg/L | 5-4791 | 0.6-13.0 | 0.07-9.60 | 1.21-20.15 | 0.01-0.35 | 0.02-3.20 | 10-175 |
| Number of Samples | 128 | 128 | 127 | 124 | 117 | 117 | 124 |
| 2. MONTGOMERY CREEK WATERSHED | | | | | | | |
| Mean, mg/L | 81 | 3.1 | 0.19 | 2.50 | 0.14 | 0.18 | 61 |
| Standard Deviation, mg/L | 65 | 2.2 | 0.10 | 1.21 | 0.09 | 0.15 | 45 |
| Range, mg/L | 19-445 | 0.2-9.5 | 0.06-0.64 | 0.96-7.10 | 0.01-0.40 | 0.03-1.00 | 8-188 |
| Number of Samples | 87 | 87 | 86 | 86 | 72 | 73 | 86 |
| 3. NORTH CATCHMENT, GUELPH | | | | | | | |
| Mean, mg/L | 77 | 10.2 | 0.20 | 2.30 | - | - | - |
| Range, mg/L | 10-1090 | 0.2-60 | 0.04-1.60 | 0.40-5.30 | - | - | 1-68 |
| 4. WEST CATCHMENT, GUELPH | | | | | | | |
| Mean, mg/L | 195 | 13.9 | 0.35 | 3.70 | - | - | - |
| Range, mg/L | 5-756 | 0.2-95 | 0.03-2.40 | 0.2-3.4 | 0.01-0.65 | - | 0-383 |

A comparison between the dry-weather and wet-weather data indicates that the concentrations of the monitored water quality parameters increased when streamflow increased. However, only weak correlations were found during storm events between flow rates and the concentrations of the monitored water quality parameters. Typical runoff hydrographs and pollutographs obtained from the Schneider Creek and Montgomery Creek watersheds are shown in Figures 7 and 8. Specifically, the first flush phenomenon was not observed in either watershed though it was noted in the two smaller catchments in Guelph. Apparently the quick hydrologic response of a small catchment favours the occurrence of the first flush phenomenon.

A correlation analysis was performed using the wet-weather water quality data collected from the Schneider Creek and Montgomery Creek watersheds. Relatively strong correlation (coefficient of correlation $r = 0.80$) was found between suspended solids and total phosphorus but not among the other water quality parameters.

The effects of total event precipitation, total runoff volume and length of the antecedent dry period on event pollutant loads were analyzed using data collected in the Schneider Creek watershed. Total event precipitation and total runoff volume were found to be the most dominant factors which determine the event pollutant loads.

### Simulation of Urban Runoff Quantity and Quality

The two objectives of urban runoff simulation are:

1. to provide input data to the GRSM model in terms of urban runoff volumes and pollutant loads on an event basis from the cities of Brantford, Cambridge, Guelph, Kitchener and Waterloo.

2. to extrapolate urban runoff pollutant loads for the populations projected for the five cities to the years 2001 and 2031.

An evaluation of several urban runoff models with respect to the above objectives lead to the selection of the STORM model (U.S. Army

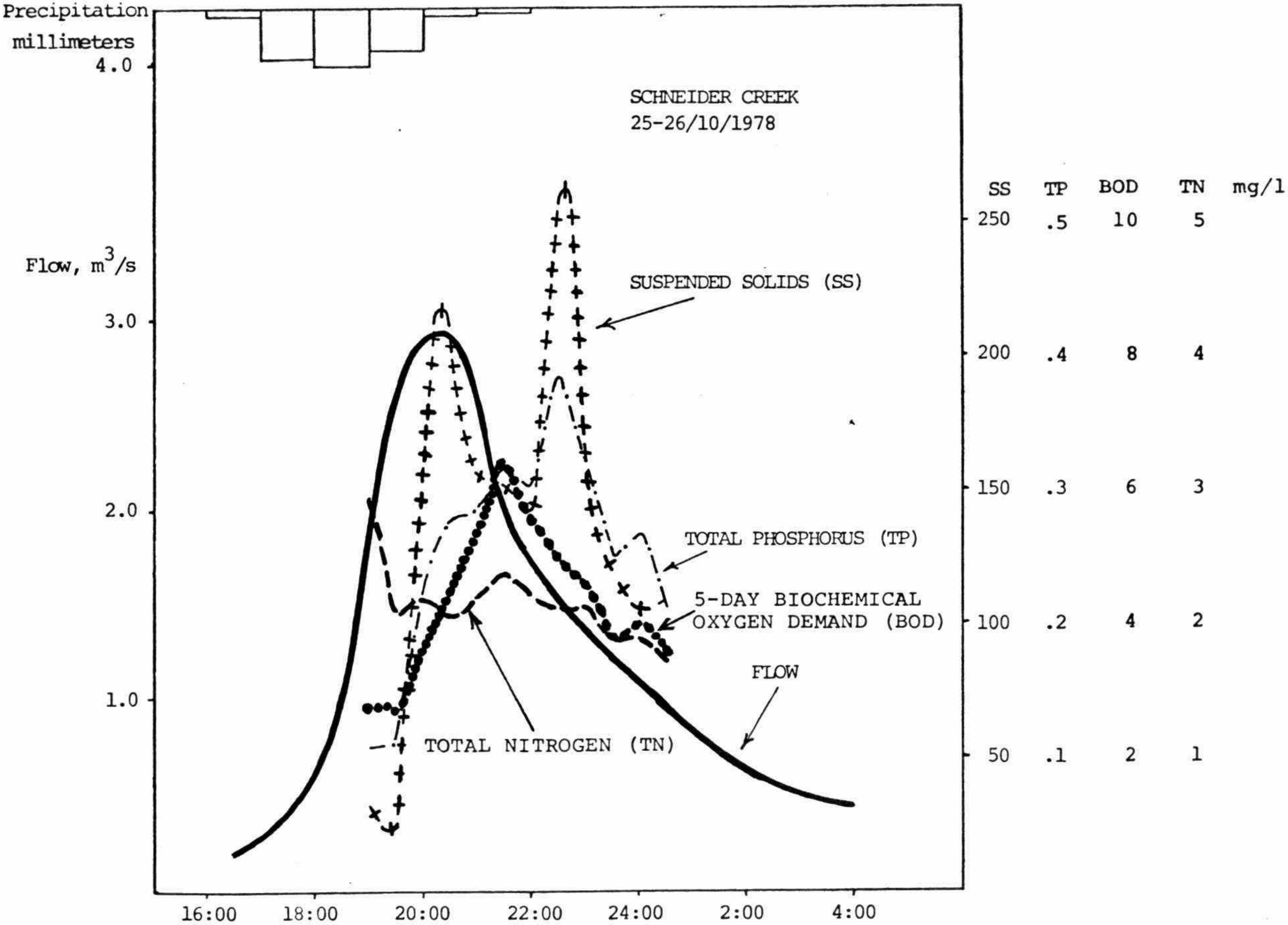


FIGURE 7. Hydrograph and Pollutographs of Suspended Solids, 5-Day Biochemical Oxygen Demand, Total Phosphorus and Total Nitrogen as Measured at the Outlet of Schneider Creek on 25-26/10/1978.

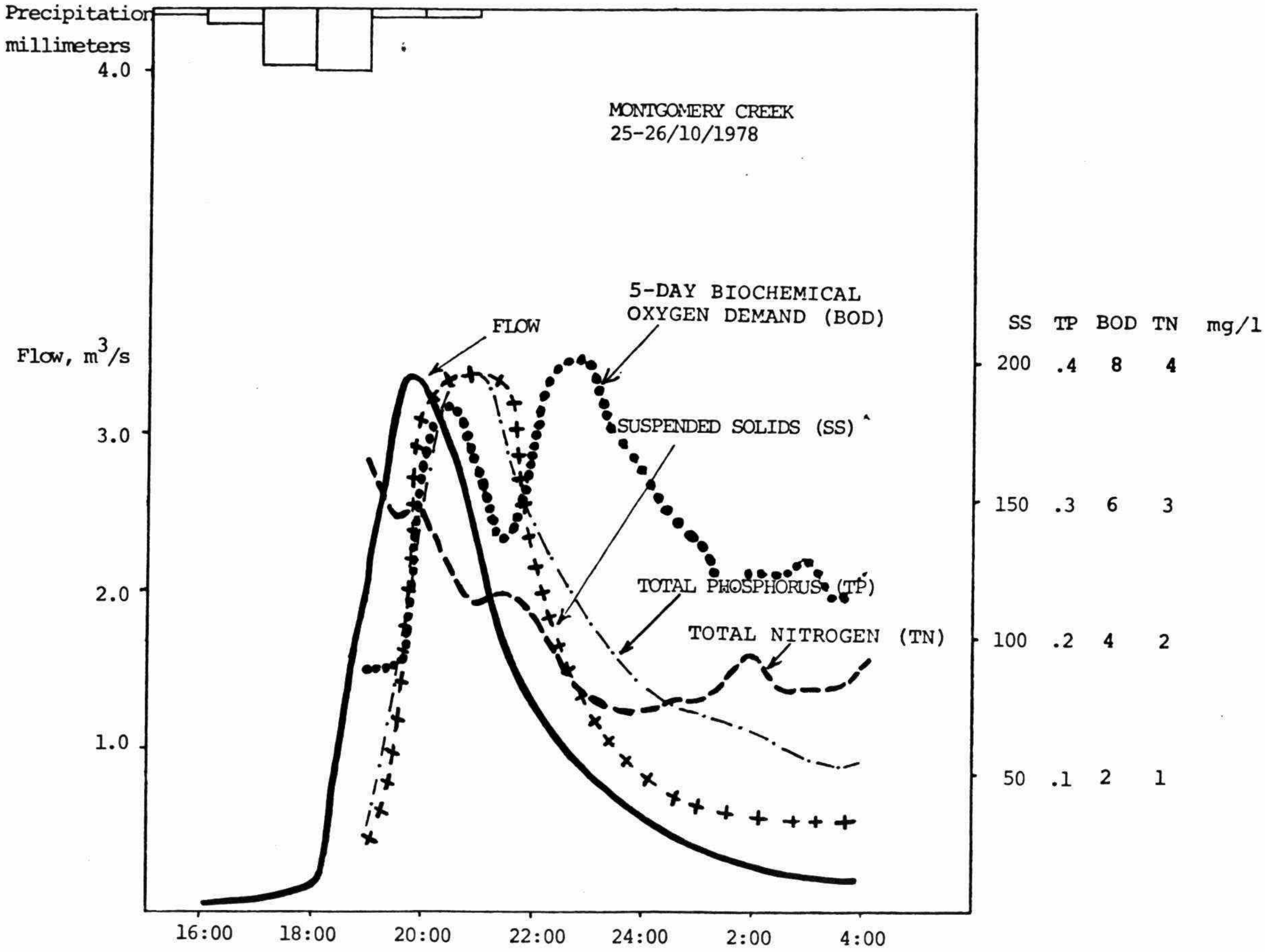


FIGURE 8. Hydrograph and Pollutographs of Suspended Solids, 5-Day Biochemical Oxygen Demand, Total Phosphorus and Total Nitrogen as Measured at the Outlet of Montgomery Creek on 25-26/10/1978.

Corps of Engineers, (1977). STORM can simulate both the quantity and quality of urban runoff. It is designed for use with many years of continuous hourly precipitation records but can be used for individual storm events. The model employs an accounting scheme that, for each storm event, allocates runoff volumes to storage and treatment and notes those volumes exceeding storage or treatment capacities. Water quality is handled as a function of hourly runoff rates, with generated quantities of pollutants allocated to storage, treatment or release into receiving waters. Statistics are generated for each event and collectively for all events processed, including average annual values for runoff and pollutant loadings. The results of model calibration and verification, with respect to both runoff quantity and quality, are presented in the following sections.

## Runoff Quantity

Fourteen storm events recorded in the Montgomery Creek watershed were used to calibrate the STORM model with respect to total event runoff volume. The results are illustrated in Figure 9.

The simulation results compare well with the measured event runoff volumes. About 79% of the deviations - the difference between simulated and measured runoff volumes - are less than 25% of the measured runoff volume. Most of the large deviations are associated with minor storm events for which measurement errors are large relative to the event runoff volume.

The coefficients of imperviousness assigned to the various urban land uses were identified to be the most significant factors which determine the event runoff volume. In order to obtain a good agreement between simulated and measured event runoff volumes, it was found necessary to use relatively low imperviousness values. The coefficient of imperviousness was reduced to 15% for residential land use. This low imperviousness value appears to be reasonable since most of the roof leaders in the Montgomery Creek watershed are not connected directly to the storm sewer system.

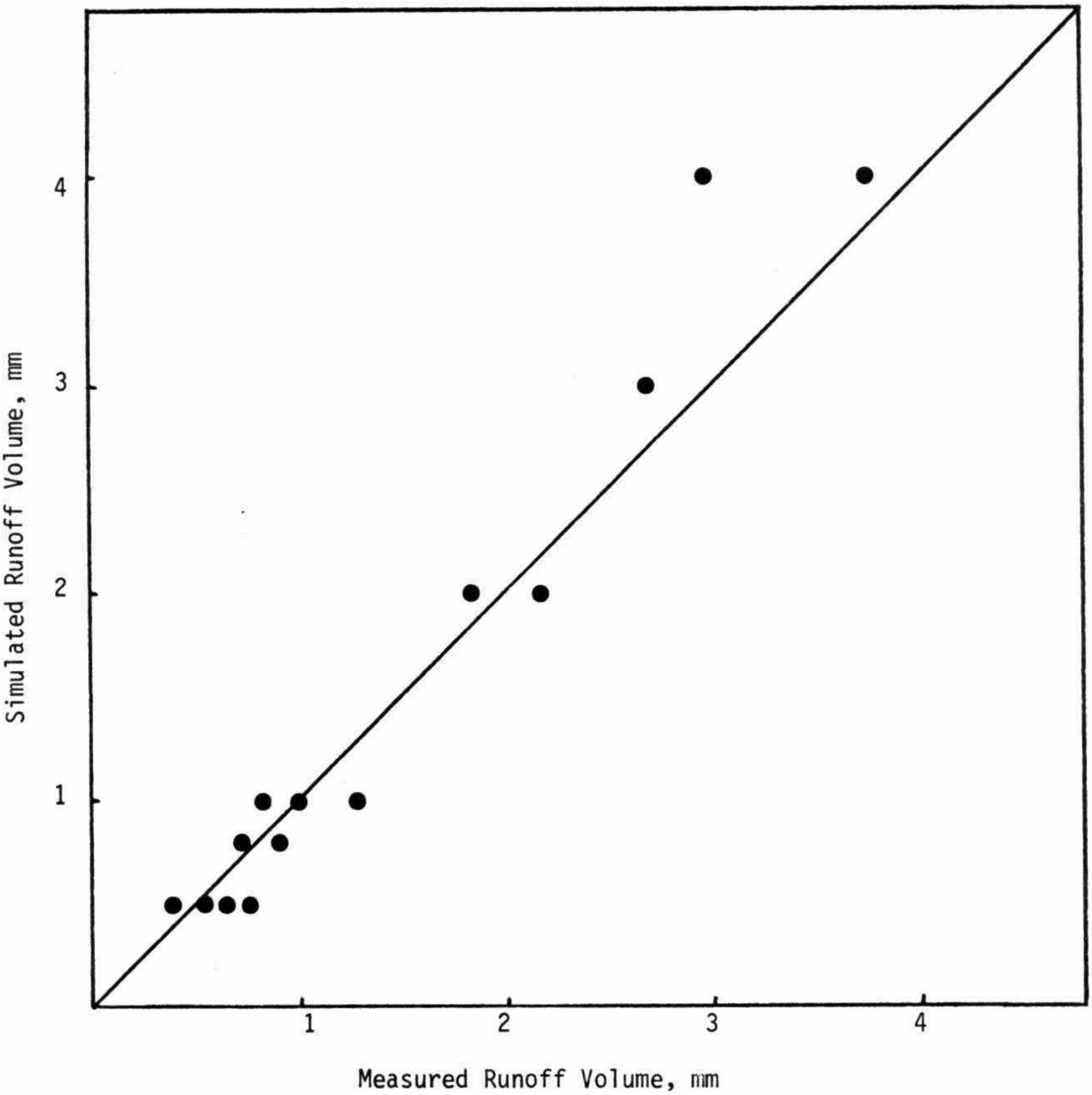


Figure 9. STORM Model Calibration with respect to Event Runoff Volume, Montgomery Creek Watershed

For model verification, the calibrated model for the Montgomery Creek watershed was used to simulate the quantity of urban runoff from the Schneider Creek Catchment. The calibrated model was adjusted to reflect the characteristics and urban land use distribution in the Schneider Creek watershed. The simulation results (Figure 10) are in close agreement with the measured event runoff volumes. About 50% of the deviations are less than 25% of the measured runoff volume.

Runoff Quality

Although runoff quality data were collected for most of the storm events recorded in the Montgomery Creek watershed (14 events), complete pollutographs are available for only four events. These events were used to calibrate the STORM model in terms of event pollutant loads. The results are given in Table 3.

The results are acceptable, particularly when one considers the simplistic approach used by the STORM model to simulate the quality of urban runoff. In most cases, the simulated event pollutant loads are within $\pm$ 50% of the measured loads.

During model calibration, it was found that the simulated event pollutant load depends primarily on three sets of parameters: the pollutant accumulation rates, the characteristics of dust and dirt and the washoff exponent. The effect of the washoff exponent on the shape of the simulated pollutograph, however, was found to be small.

The calibrated model for the Montgomery Creek watershed was used to simulate the quality of urban runoff from the Schneider Creek watershed. As mentioned earlier, the model was adjusted to reflect the characteristics and urban land use distribution in the Schneider Creek watershed. The measured and simulated event pollutant loads are compared in Table 4.

On the whole, the simulated event pollutant loads compare well with the measured loads; both are of the same order of magnitude. The

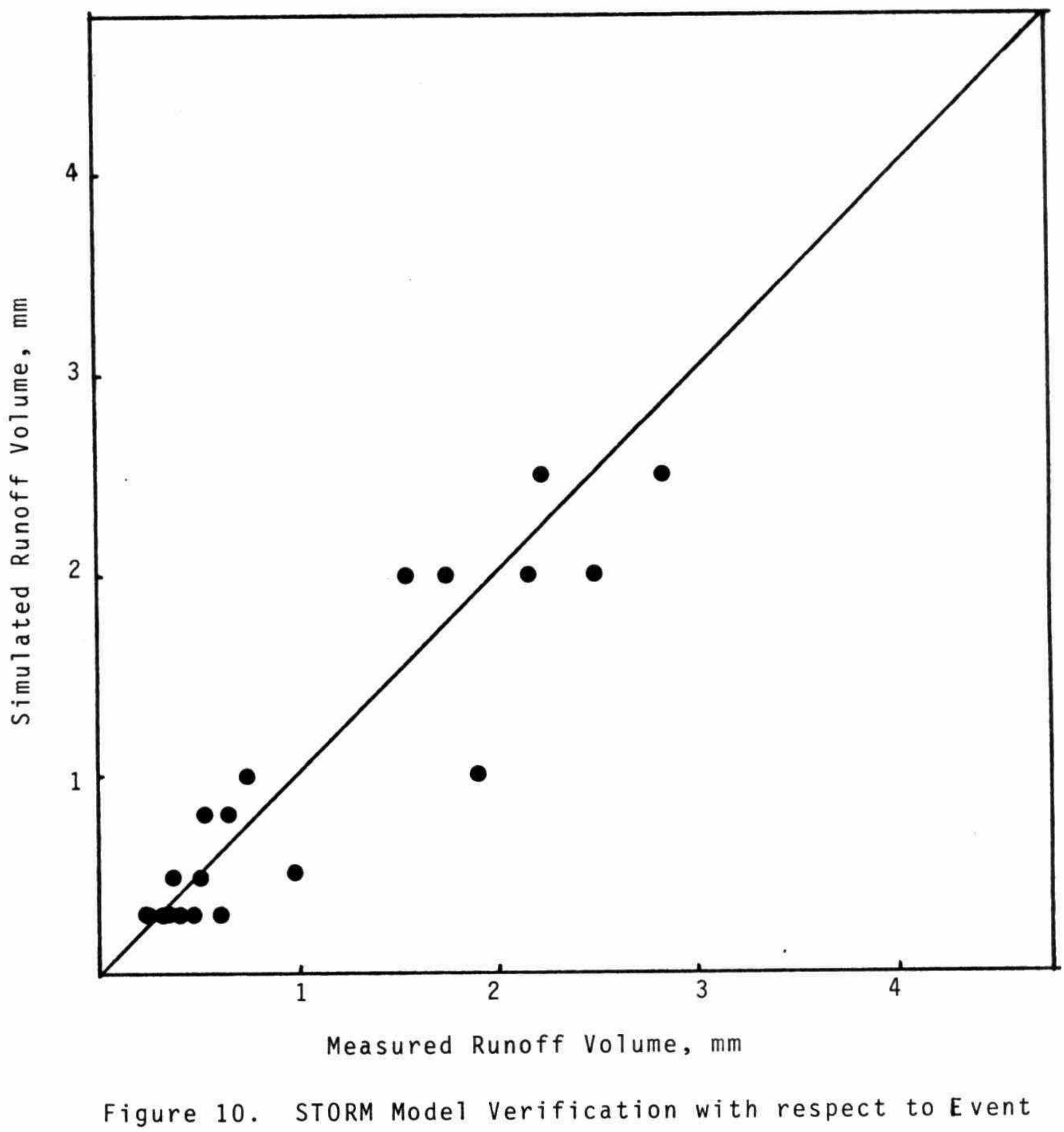


Figure 10. STORM Model Verification with respect to Event Runoff Volume, Schneider Creek Watershed

TABLE 3

STORM MODEL CALIBRATION WITH RESPECT TO EVENT POLLUTANT LOADS, MONTGOMERY CREEK CATCHMENT

| Date Storm Event Occurred | Suspended Solids kg | | 5-day Biochemical Oxygen Demand kg | | Total Phosphorus kg | | Total Nitrogen kg | |
|---|---|---|---|---|---|---|---|---|
| | Measured | Simulated | Measured | Simulated | Measured | Simulated | Measured | Simulated |
| 3/10/78 | 1909 | 2849 | 109 | 178 | 5.3 | 7.0 | 120 | 151 |
| 5/10/78 | 176 | 296 | 8 | 17 | 0.6 | 0.8 | 32 | 15 |
| 25/10/78 | 1619 | 1362 | 78 | 93 | 3.3 | 3.3 | 66 | 73 |
| 23/11/78 | 2768 | 2889 | 26 | 167 | 5.4 | 7.1 | 158 | 151 |

TABLE 4

STORM MODEL VERIFICATION WITH RESPECT TO EVENT POLLUTANT LOADS, SCHNEIDER CREEK CATCHMENT

| Date Storm Event Occurred | Suspended Solids kg | | 5-day Biochemical Oxygen Demand kg | | Total Phosphorus kg | | Total Nitrogen kg | |
|---|---|---|---|---|---|---|---|---|
| | Measured | Simulated | Measured | Simulated | Measured | Simulated | Measured | Simulated |
| 16/8/78 | 906 | 2711 | 72 | 186 | 6.3 | 6.7 | 112 | 146 |
| 24/8/78 | 2033 | 1800 | 106 | 120 | 5.5 | 4.4 | 104 | 97 |
| 14/9/78 | 18383 | 12781 | 254 | 703 | 43.3 | 31.6 | 390 | 661 |
| 17/9/78 | 372254 | 104926 | 1001 | 5006 | 857.0 | 258.8 | 3592 | 5307 |
| 30/9/78 | 1684 | 670 | 47 | 39 | 2.6 | 1.7 | 46 | 35 |
| 3/10/78 | 21924 | 8786 | 453 | 489 | 48.2 | 21.6 | 434 | 459 |
| 5-6/10/78 | 1843 | 2513 | 24 | 132 | 4.7 | 6.2 | 106 | 130 |
| 25/10/78 | 5750 | 5613 | 171 | 325 | 10.5 | 13.9 | 182 | 295 |
| 13/11/78 | 12473 | 7522 | 488 | 478 | 26.6 | 18.6 | 392 | 399 |
| 23/11/78 | 21268 | 6950 | 71 | 384 | 30.2 | 17.1 | 376 | 361 |

results are particularly good for total phosphorus and total nitrogen; the simulated event loads are within ± 50% of the measured loads. The results are not as good for suspended solids and five-day biochemical oxygen demand.

Long-Term Simulation

The STORM model was used to simulate the urban runoff and associated pollution loads for the cities of Brantford, Cambridge, Guelph, Kitchener and Waterloo for a 20-year period (1956-1975). For each city, the model was adjusted to reflect the characteristics and urban land use distribution. Parameter values for the pollutant accumulation rates, the characteristics of dust and dirt and the washoff exponent were the same as used in the calibrated model. A statistical summary of the simulation results is presented in Table 5. Simulated urban runoff volumes and loads for the five cities were used as input to GRSM model for impact assessment.

A comparison between the annual pollution loads of suspended solids, total phosphorus and total nitrogen from the five urban centres and from agricultural and sewage treatment plants within the Grand River Basin indicates that the urban percentage contribution is small (2%-6%).

## IMPACT OF URBAN STORMWATER RUNOFF ON THE GRAND RIVER

Untreated stormwater runoff may contribute a significant portion of the total pollution load entering receiving waters on an annual basis, and are often significant on a shock-load basis during wet events.

When pollutants from urban runoff are discharged into receiving waters, they may affect the water quality in several ways. Some of their effects are immediate such as bacteria contamination. Others are long-term effects such as nutrient enrichment which may lead to eutrophication.

TABLE 5 STATISTICAL SUMMARY OF SIMULATION RESULTS (1956 - 1975)

| | Brantford | Cambridge | Guelph | Kitchener | Waterloo |
|---|---|---|---|---|---|
| Area, ha | 7943 | 9080 | 7611 | 12954 | 6477 |
| Runoff as Fraction of Precipitation | 0.17 | 0.19 | 0.19 | 0.15 | 0.15 |
| Pollutant Loads, kg/ha/yr | | | | | |
| Suspended Solids | 92 | 108 | 87 | 75 | 75 |
| 5-day Biochemical Oxygen Demand | 4.8 | 5.6 | 4.5 | 3.9 | 3.9 |
| Total Phosphorus | 0.23 | 0.27 | 0.22 | 0.18 | 0.18 |
| Total Nitrogen | 9.5 | 11.1 | 9.0 | 7.7 | 7.7 |

Receiving waters such as streams, lakes and estuaries differ in the manner in which they react to similar pollutant loadings. Further, the types, extents and rates of water quality processes that occur in water bodies are controlled by the immediate physical environment as defined by climate and physiography.

The response of a receiving water to an introduced waste load depends also on its initial state. Thus, the particular response of the receiver under different initial states is basically a matter of defining the appropriate boundary conditions at the time the waste load is imposed.

The impacts of urban runoff can be also viewed in terms of major pollutants (oxygen demanding materials, suspended solids and associated contaminants, nutrients, heavy metals and bacteria) and their specific effects on the various uses of the receiving water (Singer, 1979). For example, suspended solids which find their way into a river may be deposited and become sediment. Sediment is a nuisance if deposited in navigation channels and it can reduce the capacity of drainage ways to carry high flows. Bacterial loadings from urban areas may constitute a health hazard and result in restrictions on swimming and other recreational activities.

All the above considerations indicate that the question of impacts of urban runoff on receiving waters is an issue which is dependent on specific local conditions. For the purpose of the Grand River Basin Water Management study it was decided to investigate the urban runoff impacts on the river in terms of dissolved oxygen (DO).

The strategy was:

1 - to develop a continuous dynamic water quality model capable of accepting inputs from point and nonpoint (urban and rural) sources and predicting the water quality parameters (mainly DO) under various flow regimes, sewage treatment levels and meteorological conditions.

2 - to collect continuous data on DO, temperature and other quality parameters in the Grand River Basin in order to calibrate and verify the model.

3 - to use the model in the assessment of the impacts of various inputs including urban runoff and to evaluate water management alternatives in the megalopolis area of the Grand River Basin.

## The Grand River Simulation Model (GRSM)

This is a dynamic model which utilizes O'Connor and DiToro's formulation for the calculation of DO in river systems. The model accounts for the deficits of DO caused by carbonaceous (BOD) and nitrogenous (NOD) oxygen demand, benthic oxygen demand as well as the replenishment of oxygen due to reaeration. Oxygen production and uptake (photosynthesis and respiration) as well as the day to day and seasonal growth, death and washout of three types of attached aquatic plants are calculated using an ecological subroutine (ECOL) (Kwong *et al*, 1979).

The water quality parameters include DO, BOD, NOD, nitrate, suspended solids and total phosphorus. The dynamic model simulates the effects of sewage treatment plants effluent and urban runoff under different flow conditions. The urban loadings are calculated by STORM and input to the dynamic model at five nodes representing the five urban areas: Brantford, Cambridge, Guelph, Kitchener and Waterloo, (Figure 11). Output of the model provides DO concentrations at each 2-hour time step.

## GRSM Model Calibration and Verification

The GRSM model was calibrated using actual meteorological data, river hydrology, STP effluents and upstream boundary conditions (quality and quantity) for the year 1976, from June to September. The simulated DO concentrations were compared with the continuous monitoring data for reach No.8 at Glen Christie below Guelph, reach

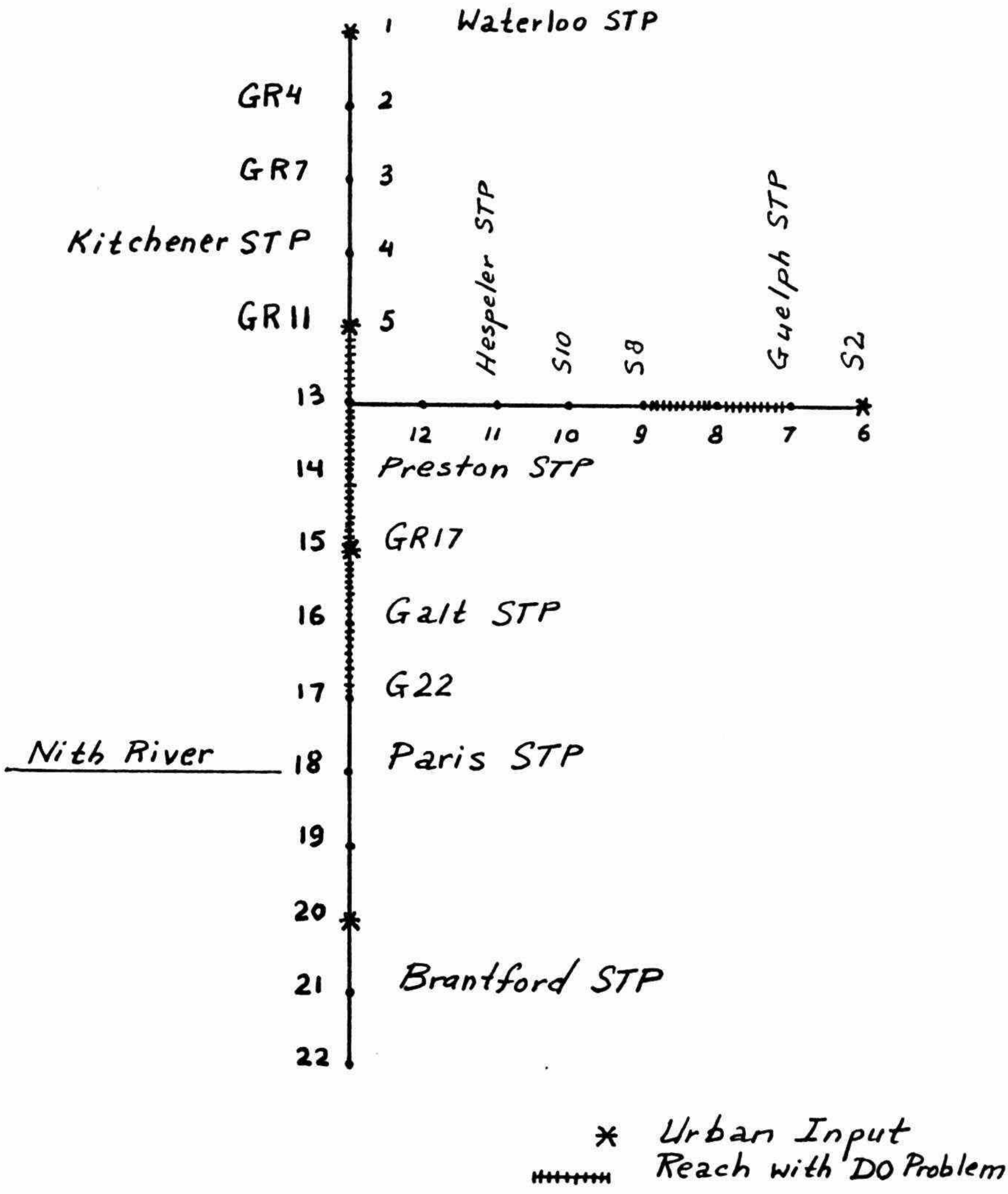


Figure 11. Grand River Water Quality Simulation Model
- Geometry of River System .

No.12 at Preston and reach No.16 at Glen Morris below Galt STP. Model parameters were adjusted until good agreement was obtained between observed and simulated DO values (Figures 12, 13 and 14).

Actual survey data of 1977 were then used to verify the dynamic model. The verification results indicate that the model is capable of reproducing the observed daily minimum DO within $\pm 1$ mg/L approximately 80% of the time. DO frequency distributions at specified levels within a month as a percentage of total time were generally predicted within 10 percentage points of the total time. In general, the accuracy of the predicted minimum DO concentrations is much better than the predicted maximum (Kwong, 1980).

Evaluation of Impact of Urban Runoff

The impact of urban runoff on the Grand River was evaluated by running the GRSM model twice for the period June-September, 1976 The first run included the urban input from the five cities whereas in the second run, the impact of this input was nullified by altering the quality of the stormwater input. This was done to maintain the same flow patterns for the two runs. Negation of the quality effects of stormwater was achieved by setting the concentrations of BOD, NOD, $NO_3$, suspended solids and total phosphorus in urban runoff to minimum values of 0.1 mg/L. A comparision of the results of the two simulation runs (Table 6) indicates that the percent of time in DO violations on the Speed River decreased by a few percentage points when urban runoff was excluded. The improvements in the daily minimum DO concentrations (Figures 15 and 16) are minor and average from 0.5 to 1.0 mg/L. The two critical reaches on the Speed River, Reaches No. 7 and 8 were still in violation for 28.1% to 55.9% of the time during the entire simulation period.

The main Grand displayed opposite trends in comparison with the Speed River. The critical reaches, Reach No. 5 (below Kitchener) and Reaches No. 13 - 16, show evidence of an increase in the percent of time in DO violations with the removal of urban input. The worst

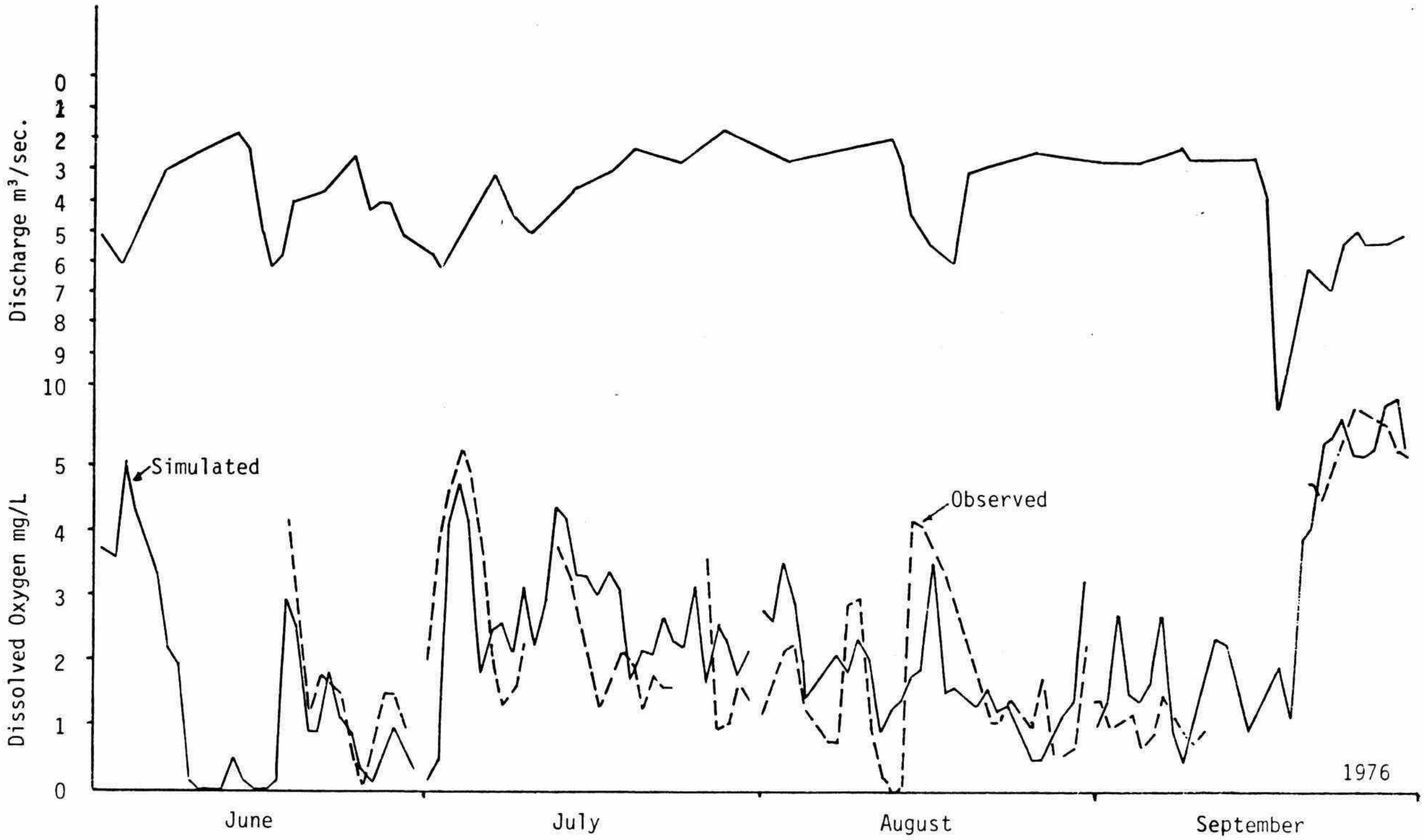


Figure 12. A Comparison between Observed and Simulated Daily Minimum Dissolved Oxygen Concentrations for Reach No.8 at Glen Christie Below Guelph on the Speed River.

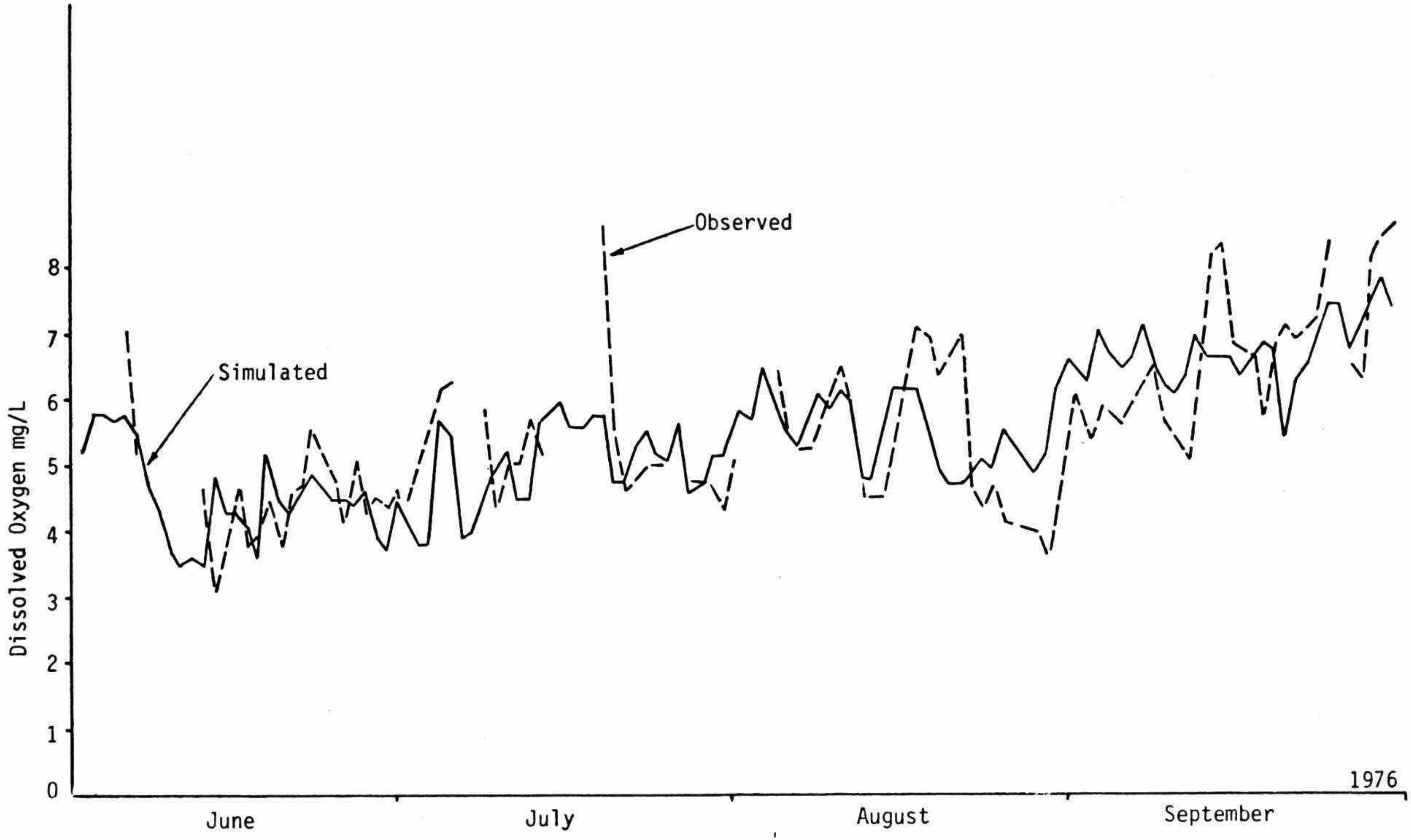


Figure 13. A Comparison Between Observed and Simulated Daily Minimum Dissolved Oxygen Concentrations for Reach No.12 at Preston on the Speed River.

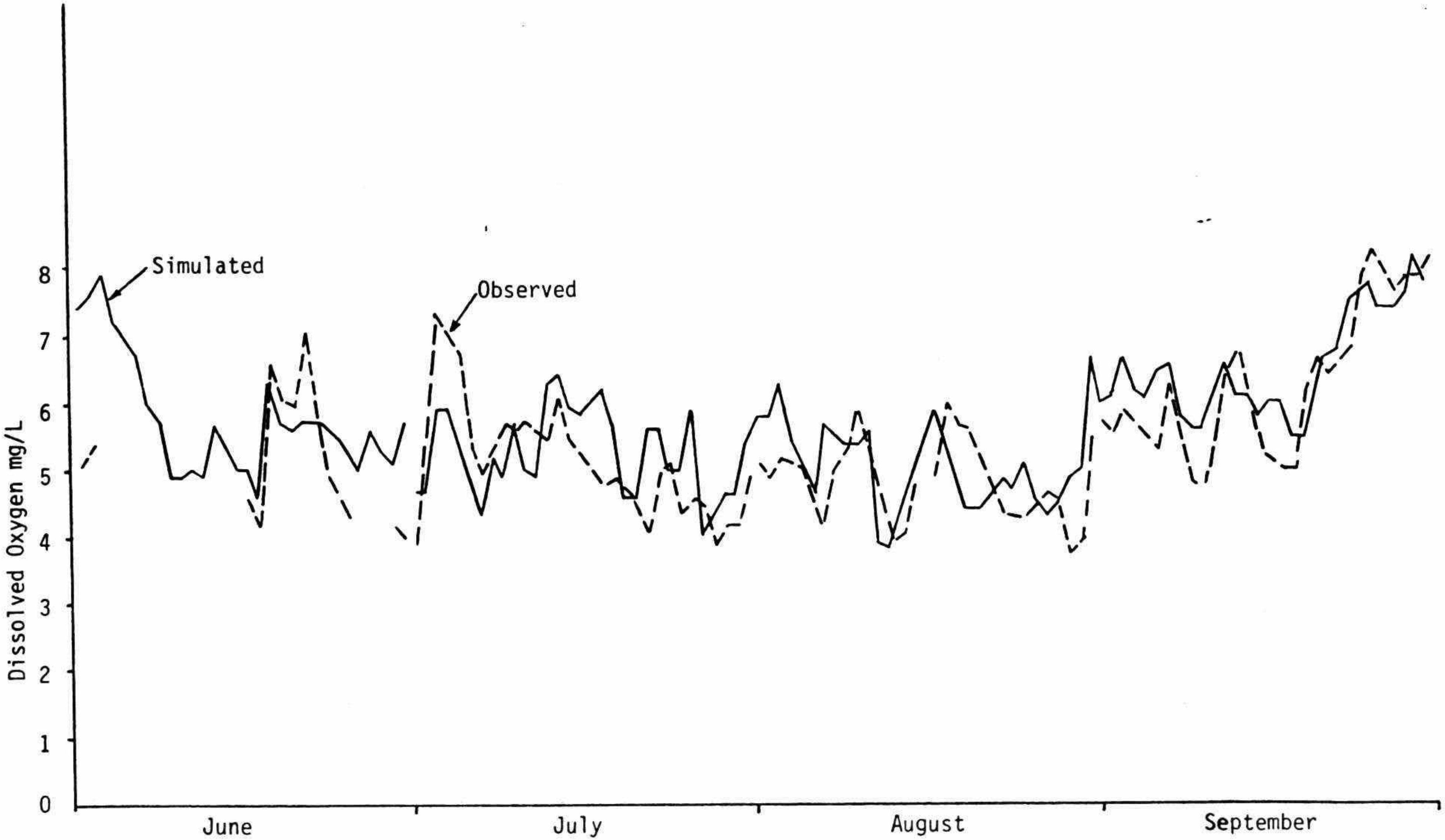


Figure 14. A Comparison Between Observed and Simulated Daily Minimum Dissolved Oxygen Concentrations for Reach No.16 at Glen Morris Below Galt STP on the Main Grand River.

TABLE 6 A COMPARISON BETWEEN THE RESULTS OF TWO SIMULATION RUNS (WITH AND WITHOUT URBAN RUNOFF) IN TERMS OF PERCENT TIME IN DO VIOLATION FOR 21 REACHES ON THE GRAND RIVER (JUNE-SEPTEMBER, 1976)

| REACH | JUNE | | JULY | | AUGUST | | SEPTEMBER | |
|---|---|---|---|---|---|---|---|---|
| | Run No. 1 | Run No. 2 | Run No. 1 | Run No. 2 | Run No. 1 | Run No. 2 | Run No.1 | Run No. 2 |
| 1 | 0.8 | 0.8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 5 | 3.6 | 3.6 | 4.8 | 5.9 | 5.4 | 10.2 | 0.0 | 1.4 |
| 6 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 7 | 30.3 | 28.1 | 36.8 | 31.5 | 43.5 | 43.5 | 29.2 | 28.6 |
| 8 | 50.0 | 48.6 | 48.7 | 41.7 | 56.5 | 55.9 | 44.2 | 38.3 |
| 9 | 2.5 | 1.4 | 7.3 | 2.7 | 2.7 | 5.1 | 3.9 | 1.1 |
| 10 | 21.1 | 19.2 | 8.6 | 7.5 | 0.3 | 6.5 | 2.2 | 3.6 |
| 11 | 1.7 | 1.1 | 4.3 | 1.3 | 0.0 | 0.0 | 1.9 | 0.0 |
| 12 | 7.5 | 8.3 | 3.0 | 1.1 | 0.0 | 0.0 | 0.0 | 0.0 |
| 13 | 1.1 | 1.7 | 3.2 | 3.8 | 4.8 | 10.2 | 0.0 | 0.3 |
| 14 | 1.4 | 1.4 | 3.0 | 4.6 | 9.4 | 18.0 | 0.8 | 2.2 |
| 15 | 0.0 | 0.0 | 2.2 | 2.4 | 7.0 | 11.0 | 0.0 | 0.6 |
| 16 | 0.0 | 0.0 | 0.0 | 1.3 | 0.8 | 4.8 | 0.0 | 0.0 |
| 17 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 18 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 19 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 20 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 21 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |

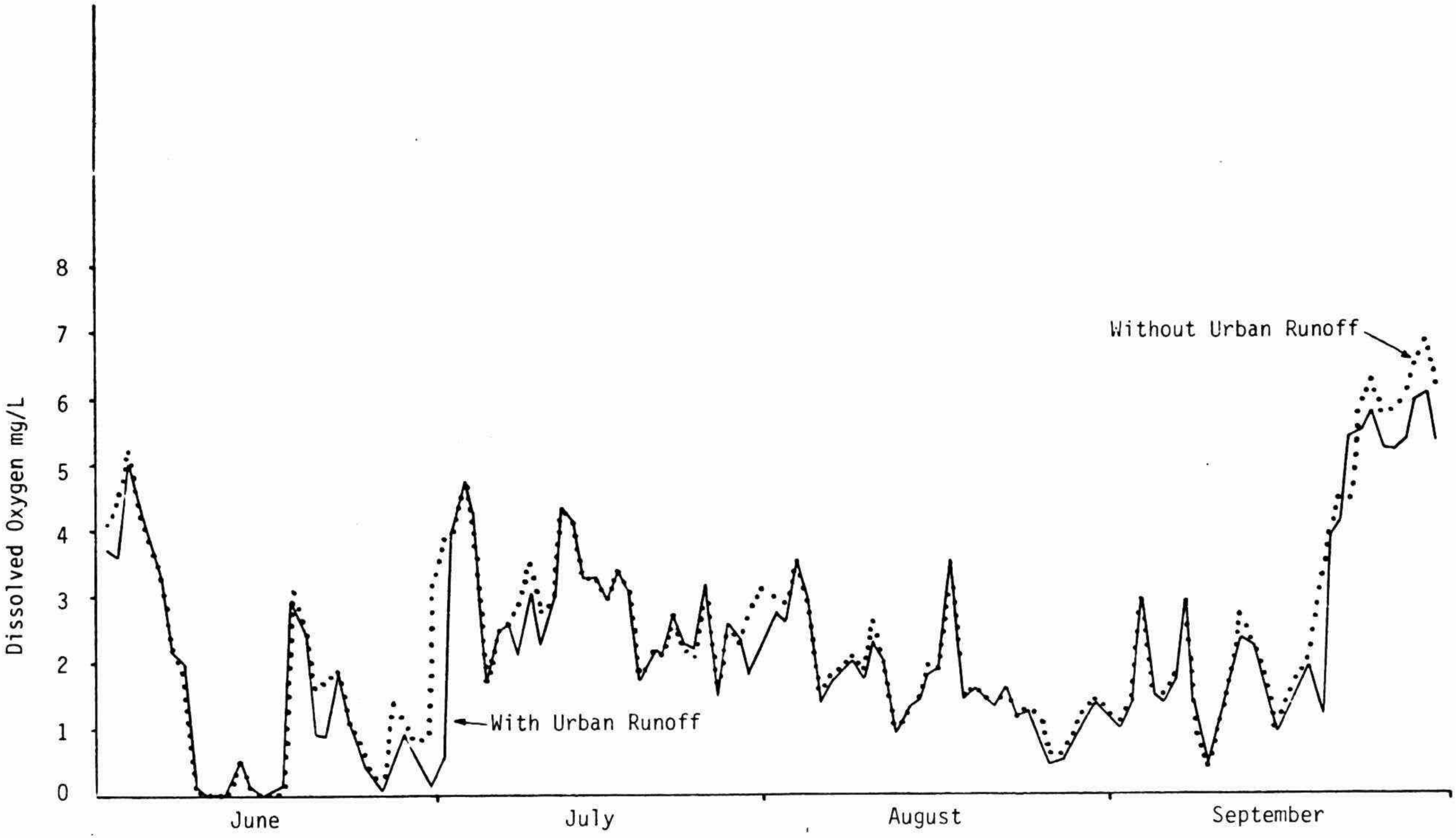


Figure 15. The Impact of Urban Runoff on Simulated Daily Minimum Dissolved Oxygen Concentrations for Reach No.8 at Glen Christie Below Guelph on the Speed River.

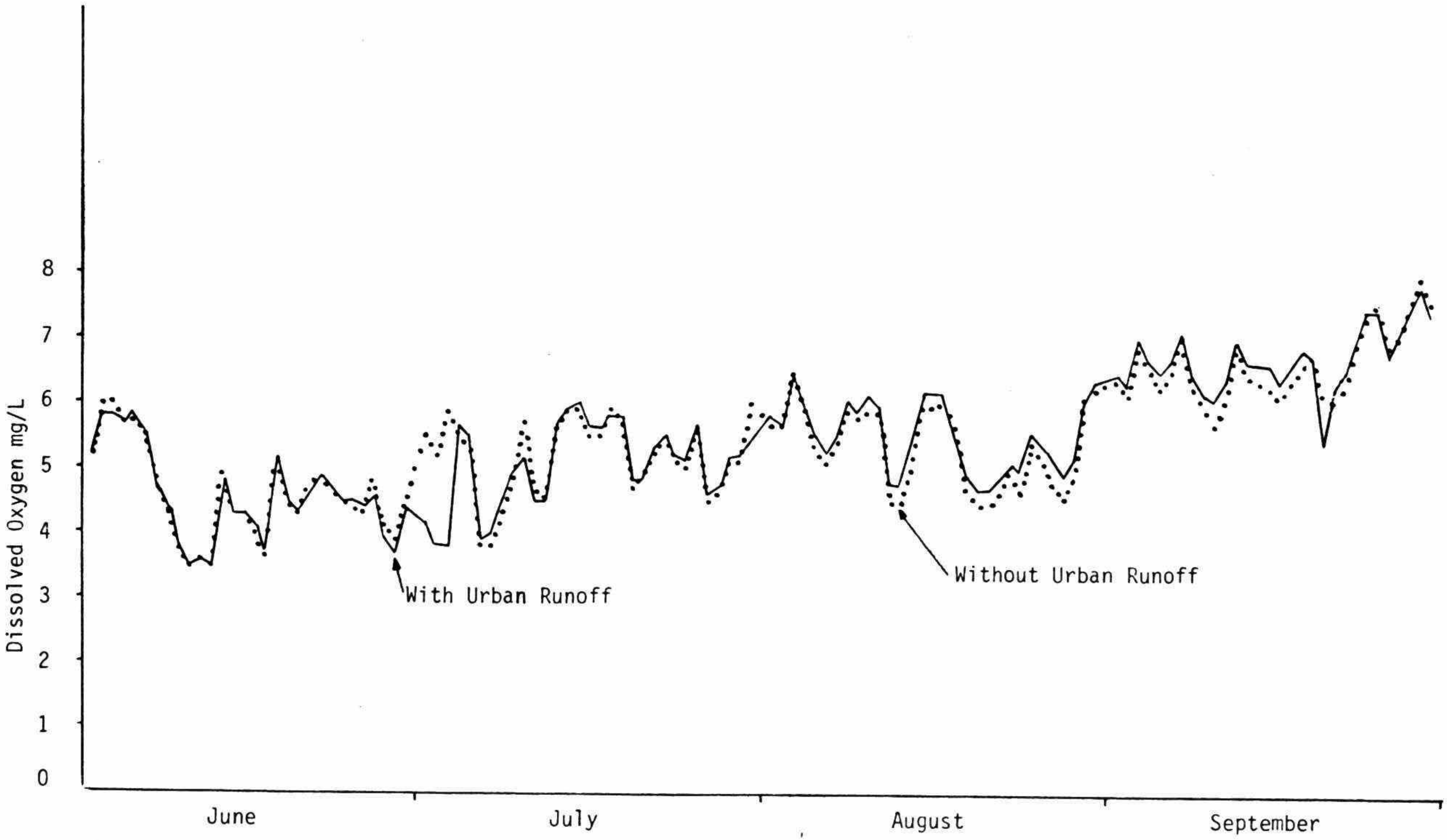


Figure 16. The Impact of Urban Runoff on Simulated Daily Minimum Dissolved Oxygen Concentrations for Reach No.12 at Preston on the Speed River.

conditions occurred in Reaches No. 5 and 13 where violations practically doubled. Nevertheless, the changes in the daily minimum DO concentrations averaged less than 1 mg/L (Figure 17). Also, the percent of time in violation for all the reaches on the main Grand ranged from 1.1% to 18.0% for the entire simulation period.

The improvement of the in-stream DO regime of the Speed River with the removal of the urban input is probably due to the reduction of total oxygen demanding load which had a positive effect due to the limited assimilative capacity of this river.

The response of the main Grand to the removal of urban input is hard to explain. It shows that the urban input is having a positive effect on the river under present conditions. A possible explanation of this phenomenon is that the main Grand is light limited and the biomass growth is affected by the available light. By reducing the amount of suspended solids in the urban runoff (second run), the turbidity of the river was reduced and more light was allowed to penetrate to plant depth, thus resulting in more biomass growth and lower DO concentrations. It should be noted, however, that the difference between the two runs in terms of the minimum DO concentrations is minor.

## CONCLUSIONS

The characteristics of urban runoff and the magnitude of the associated pollution loads from the cities of Brantford, Cambridge, Guelph, Kitchener and Waterloo are similar to those reported for other cities in Ontario.

The impact of urban runoff from the five cities on the dissolved oxygen regime in the Grand River is minor. Parts of the Speed River below Guelph and certain reaches on the main Grand between Kitchener and Brantford suffer from profuse algae and plant growth during the summer and early fall period. This results in extremely low dissolved oxygen concentrations during the night due to the respiration process. High dissolved oxygen levels are observed

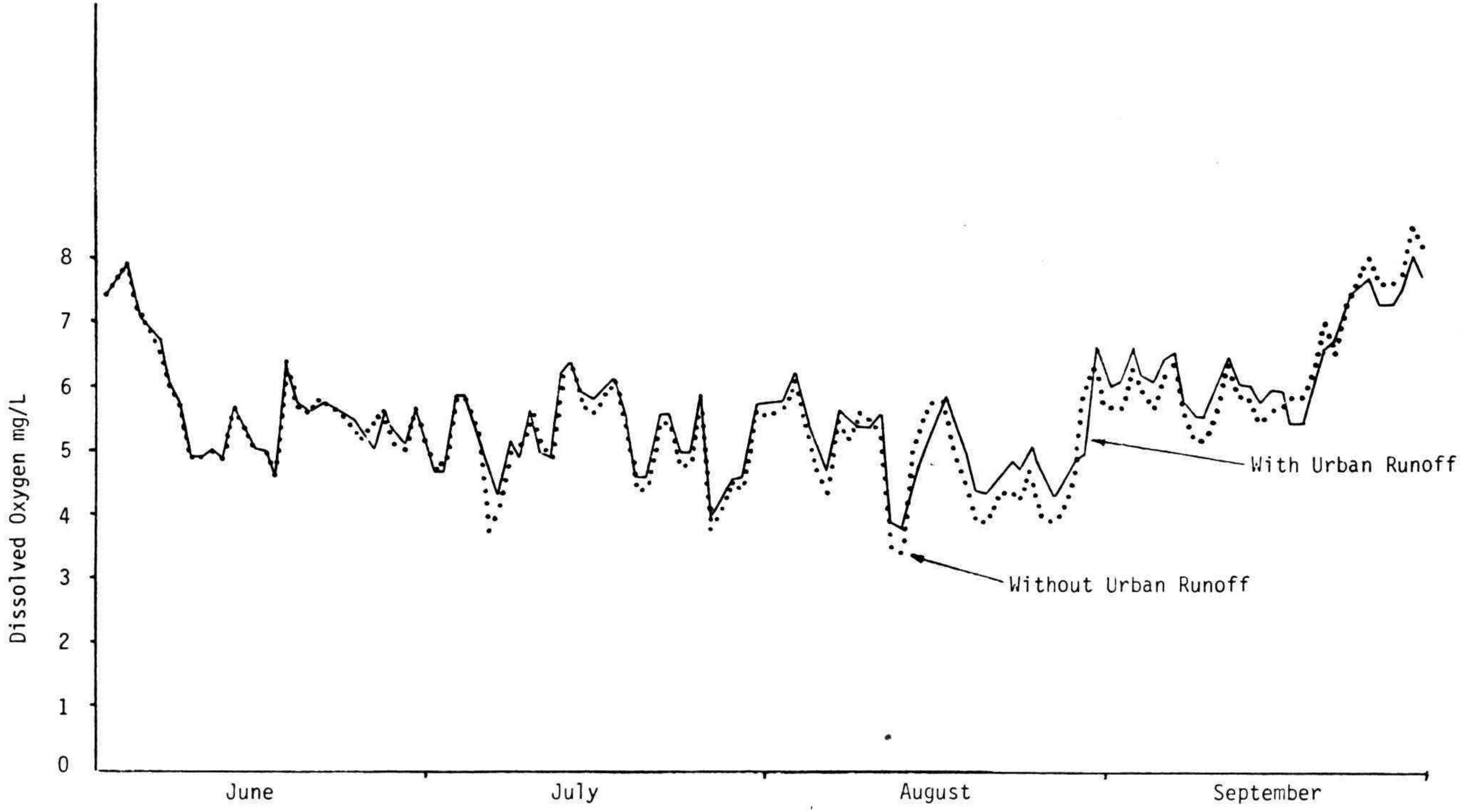


Figure 17. The Impact of Urban Runoff on Simulated Daily Minimum Dissolved Oxygen Concentrations for Reach No.16 at Glen Morris Below Galt STP on the Main Grand River.

during the day as a result of the photosynthesis process. Respiration and photosynthesis are the two dominant in-stream processes in this section of the Grand River system. Improvement of the dissolved oxygen regime would require the control of nutrient input (mainly phosphorus) from point and non-point sources. The nutrient input from urban runoff is small relative to agricultural diffuse sources and sewage treatment plants. Therefore priority for pollution control measures should be given to those two sources.

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